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PRESIDENT'S ADDRESS.

THE EVOLUTION OF THE MODERN MICROSCOPE.

Fellow-members of the American Society of Microscopists, and Friends:

The Constitution of this Society makes it the duty of the President to deliver an address during the meeting over which he presides. Custom has ruled that, while the topic selected should be scientific, it should also be of general as well as special interest, and that the treatment should be such as to interest, if possible, a general audience.

In attempting to select such a subject I have found some embarrassments, but, after due consideration, have concluded to attempt to present to you a hasty view of "The Evolution of the Modern Microscope." I shall try to trace for you the gradual development from the crystal spheroids which served our Oriental ancestors as ornaments and toys to the splendid instruments of to-day, the magic tubes that open to us treasures far richer than those of Ali Baba's cave ; that, dowering us with another sense, as it were, reveal to us the marvels of the unseen, yet material, world which surrounds us, and at times seem even to promise to lift a corner of the curtain which separates the immaterial from the material, and hides from human ken the mystery of life. I shall try to show you that almost every important step forward has been made in the face of discouraging predictions of high scientific authority that it was physically impossible, and shall also try to draw from the recital, encouragement for the future. Of course, with such a subject, I cannot hope to treat it exhaustively; neither my time nor your patience would permit. Its details would fill, indeed do fill, libraries. I can but touch upon leading points here and there, and I hope I may be able to indicate a sufficient number of these to make the evolutionary chain evident, without exhausting your interest or wearying your patience.

The microscope, in its simplest form, is a convex lens of any transparent material of higher refractive index than air. A drop of water on the end of a needle, a drop of dew on a leaf can be, and have been, used as microscopes. Lenses of rock crystal were doubtless known and used in very ancient times. Such a lens taken from the ruins of Nineveh was exhibited by Sir David Brewster at the meeting of the British Association at Belfast, in 1852.

Dutens has seen in the Museum of Portici, ancient lenses of glass of only 9 mm. (about one-third inch), focal length.

The first appearance of the microscope as an instrument of scientific research appears to have been in the latter part of the Sixteenth, or the beginning of the Seventeenth Century, and, like the invention of printing, cannot now be definitely assigned with any degree of certainty to any particular person or country. Baker, in his classical work, "The Microscope Made Easy," published in London, England, in 1743, says: "To what Accident, to what Country or to whom we are obliged for the Invention of Microscopes, it is not in me to determine: the Honor has been given by some to DREBBELL, a *Dutchman*, by others to FONTANA, a *Neapolitan*, and by others to still different People. The first appearance of them, however, was about the year 1621; since when they have been improving down to the present time."

This statement, like many others of this honest and truly scientific writer, remains true to the present day.

Zacharias Jansens & Son are said to have made microscopes as early as 1590, and it is believed to have been one of their instruments that Drebbel brought to England. It was an imposing affair, consisting of a copper tube *six feet long!* containing the lenses mounted on three brass dolphins, supported upon a base of ebony.

Fontana of Naples, in a work published in 1646, claims to have made microscopes in 1618; and, even as far back as 1592, George Hufnagel published a work on insects, illustrated with copper plates, some of which must have required the use of pretty powerful lenses.

In 1656 Dr. Robert Hooke, of London, England, published his famous work, "*Micrographia Illustrata,*" in which he describes and illustrates an immense number of objects as seen through the imperfect instruments of his day; and also describes the method of constructing lenses of great magnifying power in the form of tiny globules of glass. He also seems to have been the first to make use of the immersion principle, for he says: "If you are desirous of obtaining a microscope with a single refraction, and consequently capable of procuring the greatest clearness and brightness any one kind of microscope is capable of, spread a little of the fluid you intend to examine on a glass plate, bring this under one of your globules, then move it gently upward till the fluid touches the globule, to which it will adhere so firmly as to bear being moved a little backwards or forwards. By looking through the globule you will have a perfect view of the animalcules in the drop."

Probably the honor of being the first really great scientific microscopist belongs to Antony Von Leewenhoek, whose numerous discoveries were all made with simple microscopes, constructed with his own hands, and each consisting of a double convex lens (*not* a sphere or globe) fixed between two metal plates, and provided with arrangements for holding the object and regulating its distance from the lens. Of these microscopes he appears to have made a great number, using each for one or two objects only, and, with infinite labor, skill and patience, investigating the new world thus opened to his view. He appears to have been the discoverer of many of the larger animalculæ, such as rotifers, vorticellæ, etc., etc., of which he gives descriptions and drawings in his letters to the Royal Society, published in their Philosophical Transactions. His labors in human histology were very great and fruitful, including, as they did, investigations into the minute structure of the nerves, the discovery of the capillaries, etc., etc., all of which are recorded in his great work, "*Anatomia Interiora Rerum,*" published in London in 1687, his "*Arcana Naturæ Detecta*," Delph, 1695, and his collected writings, "*Opera Omnia*," Batavia, 1722. When we consider the difficulties under which he labored, from the imperfection of his instruments, and the fact that no method of permanently mounting and preserving histological objects was known to him, we may well stand amazed at the extent of his discoveries and the general accuracy of his descriptions. The quality of his lenses may be estimated from the fact that by the most careful and accurate measurements he could make with them, he determined the average diameter of the human blood corpuscle to be $\frac{1}{1940}$ of an inch. As the real average diameter is now known to be about $\frac{1}{3200}$ of an inch, it is evident that the aberrations of his microscopes must have been sufficient to add a coma or blurr of more than one-half its real diameter to the image of an object as small as a human blood corpuscle.

Dr. Robert Hooke, whose great work "*Micrographia Illustrata*," was published in 1656, used mostly for. his work *compound* microscopes consisting usually of a *simple* objective, a simple eye lens and intermediate simple lens, which latter was only used, however, when he wished to take in a larger field at one view than he could see with the eye lens and object lens only. This intermediate lens corresponds pretty closely to the lower lens of the common eye-pieces of the present day. When he wished to examine with greater minuteness and accuracy the smaller parts of any object he removed the middle lens, for, he writes, "the fewer the refractions the clearer and brighter the object appears."

An account of Eustachio Divino's Microscope was read before the Royal Society, in 1668. It consisted of an object-glass, a middle (field) glass and a compound ocular in which two plano-convex lenses were placed with their convex surfaces touching each other (being thus very similar to "Ramsden's Positive Eye-piece" sometimes used for micrometric work at the present day.) The tube in which these glasses were contained is said to have been as large as a man's leg, and the eye-glasses as broad as the palm of a man's hand—measurements which, though rather vague for strict accuracy, are yet sufficiently suggestive to convince one that it must have been a rather formidable affair. It had four different lengths, giving magnifying powers of 41, 90, 111 and 143 times, respectively.

In 1690, Philip Bonani published an account of his microscopes, the second being remarkable as the first example of the use of a rack and pinion for adjustment of focus, and of a substage condensor for improving the illumination.

Improvements were constantly being made in the construction and mounting of simple microscopes; the greatest, perhaps, being that of Dr. Nathaniel Lieberkuhn, of Berlin, about 1740, which consisted in placing the lens in the centre of a highly-polished concave speculum, by means of which a strongly concentrated illumination is reflected upon the upper side of the object, thus rendering it possible to examine small opaque objects with comparatively high powers, a thing impossible before, as, by reason of the short working distance of simple microscopes, the proximate sides of objects were completely shaded by the head of the observer.

This method of illumination has been adapted to the modern compound microscope and Lieberkuhns, as these concave specula are now called, are still made by some opticians and used with apparent satisfaction by some microscopists of the British school.

On the 6th of February, 1672, Sir Isaac Newton communicated to the Royal Society his "design of a microscope by reflection." It consisted of a spherical concave speculum of metal, and an eyeglass which magnified the reflected image of any object placed between them in the focus of the speculum.

Other forms of reflecting microscopes have been proposed and constructed, but little seems to have come of them.

By this time the errors arising from spherical and chromatic aberration had been discovered, and Sir Isaac proposed to remedy the latter by the employment of monochromatic illumination. The services thus conferred by this distinguished man were, however, more than offset by the publication of his opinion that the construction of achromatic lenses was a physical impossibility. How often since has the progress of microscopical improvement been impeded by the dictum of some great authority setting theoretical limits beyond which the laws of optics and the nature of light were said to make it impossible to pass. Thus would progress be brought for a time to a stand-still till some daring innovator—some Columbus of practical optics—has ventured out into the unknown and made the theoretical impossibility of yesterday the practical success of to-day. We shall meet with more of these obstructions as we trace the history of the microscope to the present day; and it may prove instructive to note that each has the support of one or more great and justly revered names, and claims to be founded upon the nature of light, the fundamental laws of optics, or some other equally immutable predicate, and that each in turn has been proved erroneous by the achievements of practical opticians, and found to be based on erroneous or insufficient knowledge, only to be succeeded by another theoretical limit, which in its turn has stood as a barrier to discourage further effort at improvement till overturned and succeeded by another; and thus it will doubtless continue "till the last syllable of recorded time."

About the year 1738, Dr. Lieberkuhn, of Berlin, devised and constructed a solar microscope for projection, and exhibited it, as well as his microscope for opaque objects, to several gentlemen of the Royal Society during his visit to England in 1740.

It appears, from Baker's elaborate description,* that Lieberkuhn's original solar microscope was not furnished with a moveable mirror, and could, therefore, be used for a very short time, only, each day. Baker leaves it to be inferred, though he does not distinctly say, that this valuable addition was due to Mr. Cuff, a practical optician in Fleet street, London. It also appears that great hopes were entertained of the services this form of instrument was to render to science. Baker says of it: † "This Microscope is the most entertaining of any, and, perhaps, the most capable of making Discoveries in Objects that are not too opake, as it shews them much larger than can be done in any other Way. There are also several Conveniences attending it which no other Microscope can have: for the weakest Eyes may use it without the least Straining or Fatigue: Numbers of People may view any Object, together, at the same Time, and, by pointing out particular Parts thereof, and discoursing on what lies before them, may be better able to understand one another, and more likely to find out the Truth, than when, in other Microscopes, they must peep in one after another, and perhaps see the Object neither in the same Light nor the same Position."

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* The Microscope Made Easy.—London, 1743, page 26.
† Ibid, page 25.

These high hopes were never realized, partly on account of its dependence upon direct sunlight, always an uncertain factor, and especially so in England, but more particularly because it could only display the *shadows* of things, instead of the things themselves. The invention of the solar microscope doubtless did much to stimulate interest in the microscope, to spread a knowledge of microscopical discoveries and to increase the number of observers; and it still survives, in a modified and improved form, in the oxyhydrogen and electric light projection microscopes, which, though they are comparatively valueless for original investigation, are of great use for demonstrating certain classes of microscopical objects to classes of students.

In 1743, Mr. Henry Baker, F. R. S., published his celebrated work, "The Microscope Made Easy," to which I have already referred, in which he describes the various kinds of microscopes then in use. The principal one appearing to be "Wilson's Single Pocket Microscope," a curious little affair, bearing a strong resemblance to the toy instrument grandiloquently advertised and extensively sold some few years ago under the name of the "Craig Microscope," but furnished with several lenses of different powers, in place of the single bead or globule of the Craig. In Wilson's instrument, which could be used for transparent objects only, each magnifier had to be used by itself; they could not be combined. There were, therefore, quite a number of them. Baker gives a list of six, varying from one-half to one-fiftieth of an inch in focal length, and consequently from 20 to 500 diameters in magnifying power, according to our modern system of computation, but from 16 to 400 diameters according to Baker, who assumed eight inches as the near point of the normal eye, instead of ten inches, as in our modern system. This instrument was originally intended to be used by holding it up to the light, as we do with pocket magnifiers at present; but Baker describes "A new Invention for fixing the Pocket Microscope, and giving Light to it by a Speculum," which appears to have been an invention of his own, and consisted of a curved arm, rising from a heavy base and supporting the microscope above a mirror attached to the base by a universal joint.

He also describes and figures "*The Double Reflecting Microscope*," an improvement, by Mr. Culpepper and Mr. Scarlett, of Mr. Marshall's large double microscope. This was really a large compound refracting microscope, the name "Reflecting" referring to the method of illumination by means of a mirror, and not to the method by which the enlarged images were formed. It was called Double, because it was a compound microscope, the rays undergoing a second refraction by means of the eye piece, after the image had been formed by the objective. It was a curious-looking affair, but in its construction and accessories we can trace the germs of much that is familiar to the microscopist of today. For instance, we can find in it in somewhat embryonic, yet recognizable forms, the eye piece, objective and draw tube, the sliding-tube adjustment for focus, the tripod stand, moveable concave mirror, bull's-eye condensor for illuminating opaque objects, a rude form of spring-clip stage, and a live box and a fish plate or box; the latter contrived with special reference to showing the circulation of the blood.

Baker does not seem to have had a very high opinion of the compound microscope, for he says of it: "Here, indeed, the magnifying power of the Object Lens is greatly increased by the addition of two Eye Glasses; but, as no Object Lens can be used with them of so minute a Diameter, or that magnifies of itself near so much as the Lenses we can use alone, upon the whole, the Glasses of this Double Microscope magnify little or nothing more than those of Mr. Wilson's single one. * * * and the chief Advantage arising from a combination of Glasses is, the Sight of a larger Field or Portion of an Object, magnified in the same Degree." *

Various modifications of the compound microscope were made from time to time, among which may be mentioned that designed by the elder Adams, and improved by his son George in 1774, and which continued to be a favorite till displaced by the achromatic instrument.

The simple microscope was also improved, notably by Dr. Wollaston, who proposed the use of his famous doublet, consisting of two plano-convex lenses, with their plane sides towards the object. The two lenses acted as one, and gave much better definition than a single lense of the same power.

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* Op. Cit., page 40.

Thus, for a time, the single microscope retained its ascendency, but a change was in progress. Euler, the great Swiss mathematician, had demonstrated the incorrectness of Newton's statement that "All refracting substances diverged the prismatic colors in a constant proportion to their mean refraction," and that, consequently, "refraction could not be produced without color," and that "no improvement could be expected in the refracting telescope." John Dollond, an English optician, had pointed out an error in Euler's theorem for correcting the aberration of refracting telescopes, and had shown, experimentally, that the dispersive power of flint glass, in proportion to its mean refractive power, is greater than that of crown glass, and had succeeded in constructing an achromatic objective (for the telescope) by combining a concave lens of flint glass with a convex of crown. It was not, however, for a long time, believed to be possible to apply this system to the lenses of microscopes, their minute size being supposed to present an unsurmountable physical and mechanical obstacle.

In 1815, however, Amici, of Modena, produced his first achromatic objective, and the next year Frauenhofer, of Munich, constructed objectives for the compound microscope, which consisted of a single achromatic combination, the lenses of which were not cemented together, and the focus was long, and the power correspondingly low.

The theoretical and practical limit prophets were on hand again, as usual, and as late as 1821, we find the great French philosopher, M. Biot, writing that, "Opticians regard the construction of a good achromatic microscope as impossible," and Dr. Wollaston, at the time the highest authority in England upon such matters, gave it as his opinion that "the compound microscope would never rival the single one."

In less than two years after M. Biot's statement, MM. Seligues and Chevalier produced some compound achromatic objectives, each consisting of two or more pairs of lenses, each pair being made up of a double convex of crown and a plano-concave of flint glass.

In 1824, Mr. Tulley, of London, England, at the suggestion of Dr. Goring, made an achromatic objective, a single triplet combination, the corrections of which are spoken of as "very complete." It was, however, of low power and narrow aperture.

About this time, Amici, of Modena, who had for some years abandoned this line of investigation in favor of the reflecting principle, resumed his labors for the improvement of dioptric microscopes, and in 1827 produced an achromatic combination surpassing anything previously constructed; and from that time the principle of combining two or more series of lenses, so adjusted as to correct each others' errors, was firmly established.

In 1829, Mr. Joseph Jackson Lister published his celebrated paper showing how many of the difficulties which had interfered with the use of two or more compound lenses or systems in one objective could be overcome, and announced his discovery of his "law of the aplanatic foci." In confirmation of the correctness of his conclusions he exhibited an objective having an angular aperture of 50° in air, of which it is recorded, "it gave a large and correct field."

His plans and discoveries being utilized and applied by practical opticians like Andrew Ross and Smith, of London, resulted in the production of compound objectives which, for wideness of aperture, flatness of field, and, above all, for perfection of definition, were far in advance of all previous attempts. The combinations used varied greatly, some opticians using compound fronts, with triplets for the middle and posterior combinations, and others adopting Amici's plan of simple, uncorrected front lenses, whose abberrations were corrected more or less completely by over-correction of the middle and posterior compound systems. Amici, also, applied the immersion system to objectives of the compound microscope. By connecting the front lens with the covering glass, by a drop of fluid having higher refractive power than air, the definition was improved, the brilliancy of the image increased, and the working distance lengthened. The full value of this important device does not seem to have been realized, even by Amici himself; its advantages appear to have been believed to be confined to the diminution of loss of light by reflection at the front surface of the front lens of the objective, and the plan fell into disuse till revived by Hartnack, a German optician settled in Paris, some thirty years later.

Meantime, the increased perfection to which objectives had been brought, introduced, or perhaps I should say *revealed*, new difficulties to be overcome. It was found that an objective which performed well over uncovered objects did not do so well on the same objects when they were covered with thin glass, and *vice versa*, and even slight differences in the thickness or refractive power of the covering glass were found to affect the defining power of the best objectives, especially when they were of high power and, for that period, of wide aperture.

In 1837, Mr. Andrew Ross, the founder of the famous house of Ross & Co., of London, presented to the Society of Arts his paper on the aberrations produced by the cover glass, and the means of correcting them by varying the distance of the front lens of an objective from the other systems. The correction collar, by means of which this change of distance was effected, was at first applied in a rather clumsy way, moving the front lens and carrying it to and from the cover glass as well as to and from the posterior combinations of the objective. It was, however, a valuable improvement and a long step forward. Mr. Ross also improved upon previous formulas for objectives, and finally announced that he had, "on several occasions, obtained the enormous angle of 135°," and unfortunately added that "135° is the largest angle that can be passed through a microscope object glass." Alas, that a man who had done so much to extend the boundary of optical science should have joined the ranks of those who set limits to further advance. Fortunately, authority had less weight than in former times, and such dicta could no longer pass unchallenged.

In a little country village of this State there lived at that time a young man of a scientific and practical turn of mind, who had taken up for himself, and by himself, the study of optics, and had, even in his boyhood, made with his own hands a microscope and some telescopes, and later on had done, though without much encouragement or patronage, good work as a microscope-maker. He read Mr. Ross' paper, and not feeling satisfied with the theoretical reasoning, soon brought forth practical proof of the incorrectness of the conclusions by a dry $\frac{1}{12}$ inch objective of 146° aperture. This young man was Charles A. Spencer, now well known as the "Father of American Microscopy," and, I am glad to say, the first Honorary Member of this Society.

Soon after, Prof. Bailey, of West Point, N. Y., succeeded in resolving, with one of young Spencer's microscopes, the markings on a diatom which had resisted the best objectives which he could at that time procure from Europe. Bailey was, of course, delighted, and named the diatom after the skillful young optician, *Navicula Spencerii.* Mr. Spencer did not confine himself to improvement of the formulæ for objectives, but experimented, with much success, in the manufacture of improved kinds of glass for optical purposes, and steadily increased the excellence and aperture of his objectives, and also made stands and accessories of excellent quality.

Meantime, the improvement of the microscope had been progressing rapidly in other directions. The negative eye-piece invented by Huyghens for the telescope had been adapted to the microscope, and found to possess the great advantage of comparative freedom from chromatic, as well as from spherical aberration, though it was the correction of the latter error only that the Dutch philosopher is said to have originally had in view in its construction. The stand of the microscope also received much attention, particularly in England, where great pains were taken to make it solid and steady, and to provide it with useful accessories. Indeed, to such an extreme were these efforts carried in some cases, that some of the more costly stands of a few years ago were ponderous engines, decorated with an array of nuts, screws and handles, truly appalling to the beginner, and even, it must be confessed, somewhat perplexing to the more experienced microscopist.

The invention of the stereoscopic binocular microscope, by Prof. Riddle, of New Orleans, in 1853, and its modification by Nachet, Wenham and others, and the general adoption of Mr. Wenham's simplest form, in which only one prism is used, is considered by many as a decided advance. Without wishing to enter at present into any theoretical discussion on the subject, I am compelled to say that I do not so regard it. No form of binocular arrangement which I have had opportunity to test, is free from the objections of loss of light and diminution of the perfection of definition. On the other hand, the more imposing appearance of the double tube instrument, the convenience of using both eyes, and the strikingly stereoscopic appearance of objects properly selected and illuminated, have seemed to thousands of microscopists to more than compensate for the loss of definition, to which they have become in time so habituated as to be unconscious of its existence. On the whole, however, the effect of the invention of the binocular seems to me to have been tolerably parallel to that of the solar microscope. It interested many, increased the number of observers, but contributed little or nothing directly to microscopical science, and by accustoming microscopists to relatively poor definition, served as a stumbling block in the path of those who desired the improvement of the microscope as an instrument of precision.

During all this time inventions of various forms of stands and accessories, such as polarizing attachments, achromatic condensors, mechanical stages and what-not, were introduced in bewildering profusion. Many proved of little value, others contained the germs of future improvements, and some were of great and permanent value. Among the latter may be mentioned the introduction of the Jackson model of stand, in which the body of the microscope is supported by a curved arm attached to a great part of its length, instead of being fixed by one end in a transverse bar, Mr. Tolles' modification of the cover adjustment, by means of which the front lens remains stationary, and the back and middle systems are moved in the line of the optical axis only; his solid oculars, Kellner's orthoscopic eye-piece, Jackson's micrometer eye-piece, the revival of the plan of immersion objectives by Hartnack, Tolles, and others.

When the fourth edition of Dr. W. B. Carpenter's great work on the microscope was published, in 1868, things were in such a satisfactory condition that that eminent authority, still happily spared to the world for whose advancement he has done so much, was moved to say, "there is good reason to believe that the limit of perfection has now been nearly reached, since almost every thing which seems theoretically possible has been actually accomplished."*

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* Carpenter—"The Microscope and its Revelations," 4th Ed., London, 1868, p. 15.

In the same volume reference is made to Nobert's 19-band test-plate, as follows: "It is stated that these lines have been resolved by Hartnack's immersion system No. 10, and oblique light, as far as the *fifteenth* band in which the distance of the lines is about $\frac{1}{91,000}$ of an inch. The existence of separate lines at a still narrower interval than this is a matter of *faith* rather than *sight;* but there can be no reasonable doubt that the lines do exist; and the resolution of them would evince the extraordinary superiority of any objective or system of illumination which should enable them to be clearly distinguished." *

The lenses which were believed to have so nearly reached the limit of perfection fifteen years ago, are antiquated now, and the theoretical limit of perfection has moved forward like the horizon, and is as far off as ever.

In a letter dated Barth, February 26th, 1869, and addressed to Col. J. J. Woodward, U. S. A., Nobert expresses his belief that the resolution of the bands beyond the 15th on his 19-band test-plate, is a *physical impossibility*, basing his opinion upon Frauenhofer's formula with regard to spectra produced when light is permitted to fall upon closely ruled parallel lines.

"His formula is $\sin x = \frac{\lambda}{b}$, if by λ we designate the length of the undulations, by b the distance between two lines of the grating, and by x the angle of the refracted rays, gives for $\sin x$ an impossible value when b becomes less than λ."

Col. Woodward comments on this as follows:

"If the view taken by Nobert of the significance of Frauenhofer's formula is correct, the shortest wave length in the visible part of the solar spectrum would appear to be the measure of the smallest dimension we can ever hope to render visible by means of the microscope." * * * Nobert himself appears to have entertained some little uncertainty as to his own deductions, for he writes: "I am, therefore, very anxious to learn whether in resolving the lines of the test-plate we shall be able to progress beyond the fifteenth band. It would be a very important step, *and one which would warrant the hope of further improvement of the microscope.*"†

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* Op. Cit., p. 180.
† M. M. J., London, 1869, p. 290.

Within a few weeks after the receipt of this letter, Col. Woodward had succeeded in resolving with a new Powell & Leland $\frac{1}{16}$ in., all the bands on the 19-band test-plate, including the 19th, in which the lines are 112,295 to the inch. The theoretical limit was passed, and the hope of still further improvement of the microscope has proved to be well founded. In point of fact, I believe that the lines had been resolved before by Messrs. Stodder and Greenleaf, with a Tolles $\frac{1}{10}$, and that the late Edwin Bickwell had seen the 19th band resolved in Mr. Tolles' room on Hanover street, Boston, with a Tolles $\frac{1}{6}$, in August, 1868.

In the *Monthly Microscopical Journal* (London) for July, 1871, page 36, Mr. Tolles gave a cut and a paper on "Experiments on Angular Aperture," in which he figures the front of his clinical objective, in which the front of the objective becomes the stage of the microscope, a drop of the fluid to be examined being applied directly to it and thinned out by pressing on a cover-glass or preferably a plano-convex lens, nearly hemispherical. An angle *in glass* of 110° was claimed for this arrangement of objective and illuminator.

Mr. Tolles concludes his paper with the following pregnant words: "The convenience of using an incidence of only about 50° to 60° on each side of the axis, instead of nearly 90°, is evident enough. That this plano-convex lens fixed in the centre of the stage, perhaps preferably made achromatic, will be utilized as a condensor, there seems no doubt. In my own hands it seems to doubly demonstrate difficult tests. Certainly the use of immersion condensors is abundantly indicated in the above simple experiments." This was the beginning of the famous aperture war, Mr. Wenham, Dr. Piggott, John Mayall, Jr., and others joined in, and the din of battle resounded for three years or more. Mr. Wenham took the position that not more than 82° in glass could be utilized, that being equivalent of 180° in air, which is, of course, the limit for dry lenses. In the M. M. J., for March, 1872, Mr. Tolles has a paper on "The Refractive Powers of Peculiar Objectives," with a figure showing how an aperture of 130° in glass can be obtained by means of a tiny hemispherical front added to a dry lens of 130° air aperture, and under date of December 29th, 1871, in a letter published in the M. M. J. for March, 1872, refers to his first article thus: "My proposition is that the balsam mounted object can, in the case of the immersion objective, be viewed with the advantage of an angular pencil actually transmitted through the object of approximately 110°, more or less. But it should be particularly noted that this is not allowed for water as the medium instead of air above the slide-cover, but instead of air a medium approaching closely the refractive power of glass."

Here was an advance; Mr. Wenham's theoretical limit of 82° in glass was passed and the principle of homogeneous immersion first announced.

In August, 1873, Mr. Tolles constructed for the United States Army Medical Museum a three-system $\frac{1}{10}$ with an aperture in glass of 110°+.

Mr. Tolles furnished the elements of the formula for publication and the objective is figured and described by Col. Woodward in the M. M. J. for September, 1874. Mr. Renel Keith computed the course of the rays through it and found the aperture in balsam to be 110° 35′ 10″, and the spherical aberration when so adjusted to be practically *nil.* Dr. Woodward tested this lens with balsam immersion and considered the definition unmistakably better than with water immersion. Here was homogeneous immersion *in practice.*

In August, 1873, Mr. Tolles made his first duplex front or four-system immersion objective, a $\frac{1}{5}$ of 110° balsam aperture, and in November, 1873, the famous Crisp $\frac{1}{6}$, balsam angle 100° and upwards. This was purchased by Mr. Crisp, Secretary of the Royal Microscopical Society, and measured in various ways by Mr. Wenham, who denied Mr. Tolles' claim of more than 82°, balsam aperture.

In the M. M. J. for January, 1871, Mr. Wenham had written: "The same optical law that limits the aperture of any object glass to near 82° in a balsam-mounted object also determines the angle *in the lens* at which the rays diverge after being refracted from the plane surface of the front," and in the M. M. J. for March, 1871, "I challenge Dr. Piggott, or any one else, to get through the object-glass with the immersion front, a greater angle, or any portion of the extraneous rays that would in the other case be totally reflected, *as no object-glass* can collect image-forming rays beyond this limit."

Here was the theoretical limit firmly set. Mr. Wenham had issued his bull (taken either in the Papal or the Hibernian sense), and challenged the world to dispute it. The Crisp $\frac{1}{6}$ was Mr. Tolles' reply, and the methods used to measure it, so as to make it conform to Mr. Wenham's limits, are instructive, if not edifying, to read of. Finally, Mr. Tolles furnished the elements of this formula also, and Mr. Keith's computation of the aperture when used with balsam (homogeneous) immersion, and so adjusted as to be practically free from aberration, gives a balsam angle of 110° 11′ 40″. Mr. Keith's computation and a diagram of the objective are printed in full in the Journal of the Royal Microscopical Society for June, 1878, page 142, *et seq.*, and the same number contains an article by Prof. Stokes, of Cambridge University, England, demonstrating mathematically that an aperture of 180° in glass is theoretically possible.

Thus the theoretical limit was again passed and a new road to improvement of the microscope pointed out. That improvement has been made cannot be doubted by any one who has seen the later productions of Zeiss or Powell & Leland in Europe, or Tolles, Spencer, Gundlach or Bausch, in this country. The Crisp $\frac{1}{6}$ is already antiquated, and its angle of 110° balsam does not seem excessive in these days of homogeneous immersion objectives of 136° to 140° balsam angle. We have still some advance to make before reaching the present theoretical limit of aperture of homogeneous immersion objectives, viz.: 180° in Crown Glass, but we are met with a limitation of another kind,—the formula for the limitation of visibility deduced by Helmholtz. This gives for a dry lens of extreme aperture one-half the wave length as the limit, that is for the mean rays of the spectrum about 96,400 to the inch, and for a homogeneous immersion objective of 180° balsam angle, 146,528; or, if the extreme blue ray near Frauenhofer's line H^2 were used pure for illumination, about 193,000 to the inch. The formula as given by Mr. J. W. Stephenson, F. R. M. S., in the J. R. M. S. for December, 1879, is—

$$a = u \ \mathrm{Sin}\ w$$

in which u=refractive index, and
$w = \frac{1}{2}$ the angle of aperture.

Mr. Stephenson gives a table of theoretical resolving powers of various objectives calculated by this formula for the mean ray, line E.

The question arises, is this limit any more firmly founded in fact than that of the Frauenhofer formula which preceded it? I cannot say; but some recent experiments made here in Elmira, by Dr. Up de Graff on Fasoldt's test-plate with American homogeneous immersion objectives, made by Messrs. Bausch and Gundlach, respectively, seem to disprove its correctness. I can only say that I would not absolutely discredit a reported resolution simply because it exceeded the limit assigned by this formula to the aperture of the objective used. Nor would I discourage an optician from efforts for further improvement of his lenses because their performance had already reached the limit assigned to their aperture in Mr. Stephenson's table. Far sooner would I quote what President Barnard, of Columbia College, wrote to Col. Woodward in reference to Nobert's deduction from the Frauenhofer formula:

"With an objective that takes in a cone of an angle of from 140° to 175°, it is nonsense to talk of this question as one settled by theory. We shall continue to see closer lines as microscopes and modes of illumination are improved."

The lesson then that I would draw from this glorious history of struggle and triumph over apparently insurmountable obstacles is: The end is not yet, absolute perfection can never be achieved but may be constantly approached; the horizon of yesterday is the halting place of to-day—the future holds for the coming optician triumphs as brilliant as any of those in the past; and the time will come, nay, is perhaps close at hand, when the best microscopes of to-day will be as antiquated as the instruments with which Hooke, Leewenhœck and Ehrenberg made their great discoveries are to-day.

In saying this I have no wish to be understood as underrating the present achievements of our microscope-makers. No one can have a deeper sense of the obligations we are under to Tolles, Gundlach, Bausch, Spencer and others in this country, and to the Becks, Ross, Hartnack, Powell & Leland, Zeiss and Abbe, in Europe, for their exquisite lenses, and to Bulloch, Zentmayer, Sidle and others, for the elegant and convenient design and very perfect workmanship of their stands and accessories. I feel, too, the obligations imposed upon us to make good use of the improved means thus placed at our disposal; not to let our zeal decrease as the perfection of our armamentarium increases. Of what use is the constant improvement of the microscope, unless a corresponding improvement is seen in the work done with it? Let me say, too, that in dwelling particularly upon the advances made here in America, I have no desire to overlook or detract from the good work done abroad. In showing that the first homogeneous immersion objectives were made here, I would not deprive Mr. J. W. Stephenson of the credit due him for first bringing prominently into notice the importance of the principle involved, nor from that due Prof. Abbe for his labors in rendering it generally available; but through the number, influence and excellent organization of scientific societies in Europe, work done there is very fully recorded and widely published, while work done here is too often overlooked and forgotten.

Let it then be the duty of this Society to encourage further effort on the part of microscope-makers, to record their successes, and, above all, to make such use of the products of their genius and skill that the boundaries of knowledge may be enlarged, new facts discovered and old errors corrected; and if the future student, in turning over the pages of our proceedings, shall find there recorded the struggles and triumphs of our opticians, and the discoveries of our working microscopists, then this Society will not have existed in vain.

APPENDIX

It was my intention and desire to include as part of the foregoing address a history of microscope-making in America, and with that end in view I wrote to all the principal makers, requesting them to give me authentic facts. So few of them complied that I was obliged to give up my design, but have concluded to give here as an appendix the leading facts in the lives of those makers who complied with my request, as I believe they have a historical value, and so good an opportunity for putting them on record may not soon occur again.

CHAS. A. SPENCER.

The story of this eminent man's life has been so fully told in Prof. H. A. Smith's eloquent memoir (published in this volume of the Proceedings), as to render any further reference to it here not only unnecessary but superfluous.

ROBERT B. TOLLES

First engaged in the construction of Microscopical Apparatus in the village of Canastota, N. Y., in 1853. Among his devices may be mentioned the form of cover correction for objectives, in which the back and middle combinations *only* are moved, the front remaining entirely stationary. Mr. Spencer had previously devised a form in which the linear motion was confined to the back and middle combinations, but the entire optical system, back, middle and front *revolved* in the operation. Mr. Tolles' plan was subsequently adopted by Mr. Spencer in his manufacture.

In 1854, Mr. Tolles devised his *solid eye-piece*, a most admirable arrangement for high powers In 1857 he made his first immersion objective. In 1868 he constructed objectives with two fronts, one to be used as immersion, and the other dry.

In August, 1873, he constructed an immersion $\frac{1}{10}$, with greater aperture than that corresponding to infinitely near 180° air (the extreme limit for a dry lens.) This was a three-system $\frac{1}{10}$—now famous as the Museum $\frac{1}{10}$—and had an aperture of more than 110° balsam, (or 1.25 N. A.) The same month he made his first lens of the duplex front pattern or formula for Dr. J. J. Woodward, of the U. S. Army Medical Museum. It was a $\frac{1}{5}$ immersion, made to work in glycerine, and had an angle of 110° in balsam. Both these lenses were homogeneous immersion lenses, as they gave best results when immersed in soft balsam, the index of refraction of which had been brought as closely as possible to correspond with that of optical crown glass, viz: 1.525.

Mr. Tolles is the author of many other devices, among which may be mentioned his stereoscopic binocular eye-piece semi-cylinder and hemispherical illuminators and traverse lens devices for utilizing beyond 1. N. A. of immersion objectives, several forms of mechanical stage of extreme thinness and delicacy of motion, and several improved forms of microscope stands. Mr. Tolles still lives, in fair health and undimnished possession of his mental and physical powers, and continues to produce fine optical work of various kinds, in Hanover street, Boston, Mass.

ERNST GUNDLACH

Was born in Pyritz, Prussia, 1834; was educated there and in Berlin, where he took a course in one of the leading workshops (C. Lewert) to learn the trade of philosophical instrument-maker; afterwards working with other firms, and always choosing those who were doing their own optical work, in the hope of adding practical knowledge to the theoretical principles of optical science with which he was already familiar. On account, however, of the habit of opticians of keeping their methodsof work strictly secret, young Gundlach learned little or nothing of practical value in this special line, and, in 1866, he started optical work for himself, knowing nothing of the methods of others, except that emery is used for grinding, and rouge for polishing lenses. Technical difficulties soon presented themselves, only to be overcome by the enthusiasm of the young optician, and in about six months he had completed his first microscope, with three objectives and two eye-pieces. This instrument was purchased by Prof. Berg, of the University of Berlin, who, though a stranger to Mr. Gundlach, recognized the fine quality of his work. The next year he exhibited at the Paris Exposition his glycerine immersion objectives, and received therefor a special medal. This Mr. Gundlach believes to be the first instance of the intentional construction of objectives for use with an immersion fluid of higher refractive index than water. A frictionless fine adjustment for microscope stands was another of his inventions about this time.

In 1873 Mr. Gundlach, who had already become recognized as one of the greatest of living opticians, removed to this country and located at Hackensack, N. J. His first work here was the construction of two water immersion objectives (a $\frac{1}{6}$ and $\frac{1}{16}$) for Prof. Thacker, of Cincinnati, O., which won the admiration of many very competent judges, including Dr. Woodward, of the U. S. A. Medical

Museum, Washington, D. C. In 1875 Mr. Gundlach invented his so-called "glycerine adjustment," in which, by means of a layer of heavy glycerine of variable thickness confined between the front of the anterior lens of the objective and a plane glass cover, compensation is made for varying thickness of cover glass without alteration of optical adjustment or change of magnifying power.

In 1876 Mr. Gundlach brought out his hemispherical condensor and his periscopic eye-piece, the latter being an improvement on the orthoscopic ocular of Kelner.

In 1879 he discovered a new optical principle, upon which the construction of his globe lens is based. The construction of this lens is very peculiar, consisting of a solid and perfect globe of crown glass enclosed in cement within a hollow globe of flint glass, the corrections being obtained by the thickness of the flint.

In 1880 Mr. Gundlach produced a series of homogeneous immersion objectives, having apertures of 136° in balsam (1.41 N. A.), and combining remarkable working distance with most excellent corrections and performance.

Mr. Gundlach has also made some notable contributions to the literature of microscopical optics, among which may be mentioned his discussion of numerical working distance of objectives, and a new method of measuring apertures from 87° to 180° in crown glass (1.14 to 1.52 N. A.) It will be seen that, so far as practical optics is concerned, Mr. Gundlach is an autodidact, as, from the secrecy maintained by European opticians in regard to their methods of work, he was unable to learn but little, if anything, and was forced to work out his methods for himself.

W. H. BULLOCH.

Mr. Bulloch, now of Chicago, Ill., is an Englishman by birth, and came to this country in 1851, and in August, 1853, was apprenticed to the foreman in the shop of B. Pike & Son, 166 Broadway, New York, to learn the trade of philosophical instrument making. He worked with the Pikes more or less continuously till 1864, when he went into partnership with William Wales, under the firm name of William Wales & Co. In this firm Mr. Bulloch made the stands and Mr. Wales the objectives. They separated in 1866, when Mr.

Bulloch went to Chicago and started business for himself. He made his first stand on his own account in 1867. After the great fire in Chicago Mr. Bulloch went to Boston and worked a few weeks for Mr. R. B. Tolles. He then returned to Chicago and started again on his own account, and still continues his business there. He is chiefly noted for the excellent quality of his stands.

THE BAUSCH & LOMB OPTICAL CO.

The microscopical department of this institution was organized in January, 1876, under the superintendence of Mr. E. Gundlach. The first objectives were finished in February, and the first stands in May of the same year. In March, 1878, Mr. Gundlach retired, and Mr. Ed. Bausch, (a son of the senior member of the firm), assumed charge of the microscopical department. Under his management the quality of the stands, objectives and accessories produced has steadily improved, till now their new series of homogeneous immersion objectives of extreme aperture are fully equal in all the qualities of a first-class objective to the best made elsewhere. By the extensive introduction of machinery, and the adoption of the interchangeable system they have been able to produce stands of remarkable excellence at very reasonable prices. Their principal services to microscopy may be said to be placing stands and objectives of good quality within the reach of ordinary working microscopists, their stands, objectives and accessories of the various series being of remarkable excellence for the price. Mr. Ed. Bausch, who is the responsible head of this department, is still a young man, and may be regarded as one of the coming men in practical optics, combining, as he does, German perseverance and steadiness with American enterprise. His late series of first-class objectives, his new immersion illuminator, and his various improved models of stands, &c., evince a high order of theoretical knowledge and practical skill.

I regret that the failure of other gentlemen to whom I addressed letters of inquiry to reply to my questions, renders it impossible for me to make this contribution to the history of microscope construction in America more complete from strictly authentic sources.